REMARKS

In the above-identified Office Action the Examiner has objected to claims 4, 17 and 19 because of certain noted informalities. These informalities have been corrected and, accordingly, Applicant believes the claims are not now objectionable.

In addition, claims 1, 4, 21, 24 and 25 have been rejected as indefinite for the limitation "covering ingress and egress openings" in line 14 of claim 1 and line 13 of claim 20. This limitation has been deleted from each of claims 1 and 20 and, accordingly, Applicant believes the claims now to be acceptable under 35 U.S.C. section 112.

Claims 1, 4-9, 11-13, 17-19, 21 and 24 have been rejected as unpatentable over the article by Wilson et al. in view of the patent to Pietsch and further in view of the patent to McClaren.

Applicant notes the existence of an Australian opposition to the issuance of the priority application as a patent in Australia. Since the issues are similar, Applicant submits in support of its arguments Exhibit A, a copy of a Statutory Declaration submitted by Applicant in that opposition.

Applicant believes that a discussion of the field of drying technologies is appropriate herein and accordingly presents the following:

The most commonly employed types of industrial granular, pelletized or solid shaped bulk material dryers fall within the classes of kiln dryers, packed bed dryers, fluidized bed dryers, rotary dryers, tunnel dryers, vibratory dryers and apron feeder dryers, which each have their advantages and disadvantages and will be preferred for the drying of particular feedstock material. In considering the adoption of a drying process for a

particular feedstock material there are a range of product properties or parameters that need to be taken into consideration when selecting the most suitable type, shape and size of drying apparatus to be adopted. For example, with coal pellets, the shape, size, resilience to attrition and moisture content (including level of bound or unbound water molecules) of the feedstock material to be dried are most important and these features will have a direct impact upon the selection of the most appropriate dryer apparatus. If particles within the material are relatively small or if there are some smaller particles in conjunction with larger particles or fragments of material then void space will tend to be filled, which will result in a very high pressure drop of the drying fluid across the feedstock material. In general, having a higher pressure drop across the feedstock material is to be avoided as this will contribute to inefficiency and high operational cost. Other important product properties that need to be taken into consideration include particle size distribution, physical characteristics of the wet and dry product, permissible drying temperature, probable drying time, drying system pressure or vacuum conditions, final moisture content, bulk material flowability, shrinkage, uniformity of final moisture content, final product temperature, over drying, dust recovery, abrasiveness, stickiness, combustibility, friability, bulk density, specific density, whether or not the material can be fluidized and anticipated atmospheric conditions (temperature and humidity). Further, the knowledge of the product mass (that is the bulk mass as opposed to the mass per article or fragment – known as the specific mass) will give rise to an understanding of the pressure required to pass a volume of the drying fluid through a mass of the product. Knowledge of this parameter will assist a design engineer to determine the ideal bed depth for drying of the material in question.

Having in mind the characteristics of the feedstock material to be dried a design engineer can then take into account some of the features of the drying apparatus that will be required for safe and efficient drying of the material concerned. It is clear that safe and efficient drying of feedstock materials depends very much upon utilization of a

drying apparatus that is specifically suited to the characteristics of the feedstock material. For example, a drying apparatus appropriate for drying of fine particulate material will almost certainly not be suitable for drying of a material that takes the form of larger pellets or clumps. Similarly, a drying apparatus that is suitable for the drying of a material of relatively homogenous unit size is unlikely to be suitable for drying the same material of different size or of mixed sizes, due to the impact that the size differential will have on the pressure drop of the drying fluid across the material to be dried. Further, due to differences in product properties it is unlikely that the same drier apparatus could be used for drying of different materials even if these materials have very similar unit sizes. Because of the specific requirements and characteristics of different material it is not possible to successfully adopt a drying technology for drying one material just because it has been successfully used for drying another material. For example, <u>it is unlikely that a dryer developed for drying of grain could successfully be used for drying of brown coal containing pellets</u>, even with significant modification. It is most likely that a completely different approach would be required. See Statutory Declaration of Lloyd-Smith, paragraph 6.

Overview of the present invention

The drying apparatus of the present invention is particularly adapted for the drying of brown coal pellets. Indeed, it is intended that the drying apparatus will be especially suited for the drying of brown coal pellets that have been produced by attritioning brown coal to release finely dispersed water and fracture of the coal surfaces exposing reactive molecular species to produce a plastic mass that is extruded to form pellets. Further details of this attritioning and pelletization process are provided in *Johns et al, "The conversion of brown coal to a dense, dry, hard material", Fuel Processing Technology, 21 (1989), 209-221*, filed simultaneously herein. Prior to being placed into the dryer the pellets may be conditioned with warm air to harden the pellet surface and

allow sufficient time for the new phenolic substrate cross linking reaction to commence the densification process. This pre-treatment method of forming brown coal containing pellets causes a fundamental chemical change to the coal structure which serves to free up bound water molecules. The result is that as water is evaporated from the surface of the pellets in the dryer the pellets shrink, thus expelling further water to the surface, which is in turn evaporated causing further shrinkage and expulsion of water to the surface. See Statutory Declaration of Lloyd-Smith, paragraph 10. The drying apparatus covered by the present claims has therefore been designed such that it promotes evaporation of water from the surface of the pellets, without the need for heating of the pellets. In this way, for example, Latrobe Valley brown coal which has an average moisture content of 60-65% can be dried in an efficient and low cost manner to 12-15% moisture. This process (technically evaporation rather than heating) has a low energy requirement, which is critical in any coal drying approach, as the energy input will have a direct effect on the overall cost.

As noted, the drying apparatus covered by the present application can be thought of as a low energy evaporator system, utilizing ambient air or air heated a little above ambient temperature, preferably by waste heat from a nearby industrial process. The configuration of the dryer allows sufficient free space within the drying apparatus for optimal airflow characteristics to be established to effect evaporation of moisture from the surface of the moist brown coal containing pellets. As moisture from the surface of the pellets evaporates the pellets shrink in size causing further moisture to come to the pellet surface, which is in turn evaporated. The configuration of the dryer (having corrugated plate opposed gas permeable walls with ingress and egress openings in the permeable leg) and its height to width ratio contribute to the shrinkage of the pellets as they dry and migrate to lower regions of the dryer resulting in some arching or bridging of the pellets in upper regions of the apparatus. As the pellets dry and contract in size, and have gained sufficient strength, they are released from this supported arched or

bridged arrangement and are allowed to progress through to lower regions of the dryer. However, this will only happen when the pellets have assumed sufficient hardness such that when migrating through the dryer they can withstand substantial fracture or deformation. The presence of the ingress and egress openings in the permeable leg rather than the supporting leg of the corrugated gas permeable walls also serves to minimize blockage to these openings, thus assisting to maintain an effective evaporative flow of the drying gas about the pellets. See Statutory Declaration of Lloyd-Smith, paragraph 11.

The avoidance of fracture of the pellets mentioned above is most important because of the safety issues that can arise if significant levels of fines are allowed to accumulate in the apparatus. As will be well understood, being a combustible material in the presence of oxygen, where it may not be possible to completely eliminate the presence of an initiation source such as heat or a spark, there is a significant danger of explosion or fire as the level of fines increases – fines material being significantly more combustible than bulk material. Reduction of fines production therefore not only reduces the risk of an explosion or fire, which is obviously important for safe operation and preventing loss of capital investment, but also reduces maintenance costs and minimizes the initial capital costs because there is a reduced need for expensive deflagration protection equipment to be installed. See Statutory Declaration of Lloyd-Smith, paragraph 12.

Other potential problems that can arise in packed bed drying apparatus, and which are overcome in the present invention, include the problems of blockage of airflow ducts, channelling and blowout. These problems are likely to be experienced if the features of the apparatus are not specifically designed with the characteristics of the feed stock material in mind. For example, channelling and blowout may be experienced in a situation where there is a lack of sufficient free space within the material to be dried, such that rather than operating at low drying gas pressure it is necessary to adopt

higher drying gas pressures to allow the drying gas to satisfactorily penetrate through the material to be dried. The use of higher drying gas pressures is not only inefficient but would also be likely to result in blowout of the material being dried through the slats between the baffles or louvers of the drier or channelling of the drying gas through the solid material. The characteristic of channeling is well understood in the art to result from the airflow pattern of seeking the path of least resistance. If channeling occurs, large volumes of the drying gas would pass through the channeled region with the result that the gas would not penetrate through the material to be dried and drying is ineffective. See Statutory Declaration of Lloyd-Smith, paragraph 14.

Key features of the subject invention include the substantially continuous corrugated plate gas permeable walls, wherein each corrugation comprises a supporting leg and a permeable leg that are angled with respect to each other, and wherein ingress and egress openings are provided within the permeable leg. This arrangement allows optimal airflow characteristics through the drying apparatus and overcomes problems referred to above of blockage of airflow ducts, channeling and blowout.

The cited prior art

As recited in the claims, the gas permeable walls comprise a substantially continuous corrugated plate, each corrugation comprises a supporting leg and a permeable leg angled with respect to each other, and the plenums are divided into zones of differing air stream properties.

As noted above, the Examiner has acknowledged that Wilson fails to disclose or suggest a number of key elements i.e., of the presently claimed invention. As such, the Examiner relies upon teachings in each of Pietsch, McClaren and Hess which the Examiner suggests disclose the elements not disclosed in Wilson. Significantly,

however, none of Pietsch, McClaren or Hess are in any way relate to the drying of brown coal and particularly not to the drying of brown coal containing pellets. They each relate to the drying, cooling, heating and/or aerating of grains, such as wheat (Pietsch).

As noted above, the material handling and physical properties of the material to be dried require in each case a specifically tailored solution in terms of an apparatus suitable for drying. Therefore, a person skilled in the art looking for a solution to the problem of drying pellets containing brown coal would not give any consideration whatsoever to known apparatus for the drying of grain, and would therefore not seek to locate documents such as Pietsch, McClaren and Hess. Nor would the skilled person take any notice of such teachings even if they came to the skilled person's attention. It is simply not feasible from an engineering perspective, particularly in view of the background provided above about the technical considerations that need to be accounted for in providing an apparatus and method for the drying of brown coal containing pellets, to take fundamental features of the dryer disclosed in Wilson and then individually select individual components from the completely unrelated apparatus disclosed in each of the other cited documents. Therefore the skilled person would have no reason or motivation to adopt the combination of prior art features proposed by the Examiner.

Pietsch

Pietsch is not relevant not only because it is unrelated to the drying of coal but also, rather wheat, because the disclosed apparatus includes an internal plenum.

The structure of the apparatus in Pietsch is fundamentally different to the present invention, which requires the presence of plenums on external surfaces of the corrugated side walls. In any case Pietsch does not disclose a corrugated plate that has a supporting leg and a permeable leg. In Pietsch both legs are permeable - which is an arrangement that could not work in drying coal containing pellets as there would be insufficient drying gas flow due to blockage with coal of the holes in the corrugated

plate.

Also, the path of the grain to be dried in the apparatus of Pietsch has a very narrow width, meaning that it would come into constant contact with hard surfaces. In the case of coal containing pellets this would lead to significant degradation of the pellets and accumulation of fines, which would pose a significant safety risk.

McClaren

McClaren has nothing to do with drying of brown coal but, rather an unidentified grain. Further, although it does disclose a dryer that includes plenums having zones of different air stream properties this is of no significance because McClaren also includes an internal plenum system, which is fundamentally different to the requirement for external plenums according to the present invention. Creating zones of differing air stream properties in the situation where there are external plenums could not be achieved in the same way as for the case where there are internal plenums and for this reason a skilled person would immediately reject McClaren as having any relevance to the presently claimed invention.

Hess

Hess would also not be relied on by persons skilled in the art as it also relates to the completely unrelated field of heating and drying unidentified grains. Its disclosures would therefore be immediately dismissed by a skilled person as having any relevance to the present invention.

Summary

(a) The design of drying apparatus must take into account many important parameters, and in particular must be specific for the physical and materials handling properties of

the material to be dried. A skilled person would therefore not take any consideration of art relating to the drying of grain. There is therefore no motivation for a skilled person to combine the teachings with any one or more of Pietsch, McClaren and Hess with those of Wilson.

(b) Even if a skilled person who was in possession of Wilson did become aware of disclosures in Pietsch, McClaren or Hess it would not be feasible to adopt single features from these unrelated documents and combine them with features disclosed in Wilson. The apparatus of each of Pietsch, McClaren and Hess are designed as integrated systems and it would not make any engineering sense to adopt single features from unrelated disclosures in an endeavor to solve a completely unrelated problem.

(c) The Examiner's rejection combining features from a number of unrelated documents can only work with the benefit of hindsight. This is the only means by which the specific features the Examiner has referred to could be selected to be combined from amongst a number of documents each of which discloses complex apparatus having many different features. Even if a skilled person was to chance upon the specific combination of features the Examiner has drawn from the cited art a skilled person could not have had any expectation whatsoever that such a combination could be successful in giving rise to a cost-effective and safe means of drying brown coal pellets.

Therefore, Applicant believes the claims, as amended, are unobvious in view of the cited art.

Applicant hereby requests reconsideration and reexamination thereof.

No further fee or petition is believed to be necessary. However, should any further fee be needed, please charge our Deposit Account No. 23-0920, and deem this paper to be the required petition.

With the above amendments and remarks, this application is considered ready for allowance and Applicant earnestly solicits an early notice of same. Should the Examiner be of the opinion that a telephone conference would expedite prosecution of the subject application, he/she is respectfully requested to call the undersigned at the below listed number.

Respectfully submitted,

Gerald T. Shekleton

Dated: 8 February 2011

Gerald T Shekleton
Reg. No. 27,466
Husch Blackwell LLP
120 South Riverside Plaza, 22nd Floor
Chicago, Illinois 60606
Phone: (312) 655-1511
Fax: (312) 655-1501

AUSTRALIA

Patents Act 1990

IN THE MATTER of Australian Patent Application No. 2004274520 in the name of ECT Coldry Pty Ltd

- and -

IN THE MATTER of Opposition thereto by Jott Australia Pty Ltd

STATUTORY DECLARATION

I, Matthew Lloyd-Smith of Level 17, 1 Nicholson Street, Melbourne, Victoria, 3000, Australia, do solemnly and sincerely declare as follows:

My Instructions

1. I have been provided with a copy of the Federal Court Guidelines for Expert Witnesses, which I have read and from which I understand that my role in making this declaration is to provide independent and impartial evidence that is based upon my own understanding and opinion. I have also been provided with copies of the following documents:

(a) Copy of Australian Patent Application No. 2004274520 (the ECT application), including amendments that I am informed were proposed after acceptance of the application;

(b) Copies of documents that I am informed have been relied upon by the opponent in its evidence, namely:

D1 - Jott Australian patent no. 2002311092

D2 - Roberts US patent no. 1,482,812

D3 - Duzan US patent no. 3,589,027

D4 - Kordelin US patent no. 5,671,804

EXHIBIT A

D5 - Gronert US patent no. 2,245,664

D6 - Herman - "Brown Coal", pages 320-329.

2. I have been asked to carefully consider the Federal Court Guidelines for Expert Witnesses, noting that I am to act as an independent witness for the benefit of the Commissioner's Delegate who will decide on this opposition and I have been asked to comment on the following:

(a) the types of techniques that would have been well known by persons skilled in the field for drying brown coal at the time of filing of the ECT application (25 September 2003);

(b) the process I would have undertaken in September 2003 if I had at that time wanted to devise a new apparatus for drying brown coal, and in particular, what sort of information I would have read and where I would have looked for relevant information;

(c) any differences or similarities between the invention defined in the ECT application and the inventions described in each of documents D1 to D6;

(d) whether differences between the invention defined in the ECT application and the teachings in documents D1 to D6, even if combined, would have been obvious to a skilled person in September 2003.

My Experience

3. I am a Senior Mechanical Engineer and Associate with the global consulting engineering firm Arup ("my firm"). I lead the Process Engineering Team within the Industrial Division of my firm's Melbourne office. My firm has been commissioned by ECT Coldry Pty Ltd ("ECT") to provide engineering support in the development of the ECT coal drying technology and I am the lead engineer involved in this project. I have been involved with this project since March 2008.

4. From my curriculum vitae which is shown to me now and annexed hereto as Annexure MLS-1, you will note that I graduated in 1990 with a Bachelor of Engineering (Industrial) from Monash University and I am a Chartered Member of

Engineers Australia in the Professional Engineer Occupational Category. Since graduating I have had some 20 years experience as an industrial engineer, including significant specific experience in relation to drying apparatus and processes. For example, in addition to my recent involvement with coal drying through ECT I was the project leader in relation to the design, manufacture, supply and installation of a gas fired continuous conveyer band dryer for drying extruded kaolin pellets for Imerys Minerals Australia in 2003 and 2004, I was involved in the engineering and design of a high temperature bag house for the flue gas particulate collection from a fluidised bed lime kiln fired on macadamia nut husks on behalf of Unimin Minerals in 2002 and 2003, I was the lead in the design and project engineering for the upgrade of a high temperature vertical shaft kiln flue gas exhaust bag house associated with a lime kiln upgrade on behalf of David Mitchell Limited, between 2000 and 2002, I was responsible for design and project engineering for a novelty and custom designed pistachio nut vibratory conveyer and direct gas fired drying system on behalf of APC in 2003 and 2004 and was involved with the feasibility design engineering of static and vibrating type fluid bed dryers and re-heaters for casting sand bulk product on behalf of ION Limited in 2003. Prior to commencing with my firm in January 2005 I worked for GCD International Pty Ltd as a design engineer involved with the design, manufacture and installation of process equipment, including dryers and ovens, mostly utilising gas as an energy source, from January 2003. You will see, therefore, that I have diversified experience in relation to a range of different types of drying technologies that are adapted for the drying of a variety of materials.

Drying Technologies Background

5. The most commonly employed types of industrial granular, pelletised or solid shaped bulk material dryers generally fall within the classes of kiln dryers, packed bed dryers, fluidised bed dryers, rotary dryers, tunnel dryers, vibratory dryers and apron feeder dryers, which each have their advantages and disadvantages and will be preferred for the drying of particular feedstock material. In considering the adoption of a drying process for a particular feedstock material there are a range of product properties or parameters that need to be taken into consideration when selecting the most suitable

type, shape and size of drying apparatus to be adopted. For example, with coal pellets, the shape, size, resilience to attrition, moisture content (including level of bound or unbound water molecules) of the feedstock material to be dried are most important and these features will have a direct impact upon the selection of the most appropriate dryer apparatus. If particles within the material are relatively small or if there are some smaller particles in conjunction with larger particles or fragments of material then void space will tend to be filled, which will result in a very high pressure drop of the drying fluid across the feedstock material. In general, having a higher pressure drop across the feedstock material is to be avoided as this will contribute to inefficiency and high operational cost. Other important product properties that need to be taken into consideration include particle size distribution, physical characteristics of the wet and dry product, permissible drying temperature, probable drying time, drying system pressure or vacuum conditions, final moisture content, bulk material flowability, shrinkage, uniformity of final moisture content, final product temperature, over drying, dust recovery, abrasiveness, stickiness, combustibility, friability, bulk density, specific density, whether or not the material can be fluidised and anticipated atmospheric conditions (temperature and humidity). Further, the knowledge of the product mass (that is the bulk mass as opposed to the mass per article or fragment – known as the specific mass) will give rise to an understanding of the pressure required to pass a volume of the drying fluid through a mass of the product. Knowledge of this parameter will assist a design engineer to determine the ideal bed depth for drying of the material in question.

6. Having in mind the characteristics of the feedstock material to be dried a design engineer can then take into account some of the features of the drying apparatus that will be required for safe and efficient drying of the material concerned. It is clear that safe and efficient drying of feedstock materials depends very much upon utilisation of a drying apparatus that is specifically suited to the characteristics of the feedstock material. For example, a drying apparatus appropriate for drying of fine particulate material will almost certainly not be suitable for drying of a material that takes the form of larger pellets or clumps. Similarly, a drying apparatus that is suitable for the drying of a material of relatively homogenous unit size is unlikely to be suitable for

drying the same material of different size or of mixed sizes, due to the impact that the size differential will have on the pressure drop of the drying fluid across the material to be dried. Further, due to differences in product properties it is unlikely that the same drier apparatus could be used for drying of different materials even if these materials have very similar unit sizes. Because of the specific requirements and characteristics of different material it is not possible to successfully adopt a drying technology for drying a material just because it has been successfully used for drying another material. For example, it is unlikely that a dryer developed for drying of grain could successfully be used for drying of brown coal containing pellets, even with significant modification. It is most likely that a completely different approach would be required.

Approach to Addressing an Engineering Problem and Sources of Information

7. I have been asked to comment upon my approach to addressing an engineering problem relating to drying of a feedstock material. When presented with the problem regarding drying of a feedstock material my usual approach is to initially collect information regarding the feedstock material itself, such as in relation to the physical and chemical form, and the wet and dry characteristics of the material, the final requirements of the product and whether the moisture is bound or unbound and if the form of the material can be changed, such as by pelletising or milling. The next stage of my usual approach would be to do some research in relation to known and commercially available drying apparatus or methods that have been used in respect of this particular feedstock material. Based upon the information gathered my usual approach is to conduct a mini feasibility study on some of the most likely approaches, which would involve carrying out energy requirement calculations, determining the likely volume of material to be dried, considering a range of different drying approaches, determining the likely capital cost of the drying equipment under consideration, making estimates of the drying efficiency likely to be required, doing a costing of the energy source and operational expenses and, based upon these parameters, conducting a net present value calculation of the cost per tonne of drying the material. From this analysis I would develop an initial feeling as to the

commercial viability of the possible approaches. If the costings for one of the approaches appear to be of a commercially viable order then this proposed approach would form a starting point for modifications or developments that may serve to improve the efficiency and reduce the cost of the process.

8. As I noted above, my initial work on any new engineering problem relating to drying a feedstock material is to collect information about the material itself and to research known and commercially available drying apparatus and methods used for drying the material of interest. My sources of information for this research would most likely be Perry's Chemical Engineers' Handbook (Green, D.W and Perry, R.H., McGraw-Hill, 8th Edition, 2008), which is my primary resource, a range of Engineering Journals to which I subscribe, most notably including the US publication Process Heating (BNP Media, Deerfield Illinois, USA). I would also conduct a search of technical literature through my firm's librarian, focussing upon apparatus previously used for drying brown coal and the product handing characteristics of brown coal. I would discuss the project with colleagues and may conduct a Google web based search for manufacturers of existing apparatus. I do not search or read patent documents, given that in my limited experience with reading patent documents I have not found them to be a useful source of information. On occasion when conducting a Google search a link to a patent search tool will come up. I never follow such links. In the early stages of a new project I often make contact with TUNRA (The University of Newcastle Research Associates) in view of their expertise with bulk material properties and their capability to conduct flowability tests.

9. Given my statement above that I do not search or read patent documents in the course of my initial work on any new engineering problem I do not believe that I would have located any of documents D1 to D5 if I had been working on the problem of proving an improved method and apparatus for the drying of brown coal containing pellets at around September 2003. I could certainly not have located any of documents D2 to D5 at that time, as not only are these patent documents that I would not have searched, but they do not include any reference to the drying of brown coal containing pellets, which is the terminology around which my search would have been based. I also do

not believe that I would have located document D6 in a search conducted in September 2003 as although it does make reference to brown coal, it does not refer to brown coal containing pellets (it relates to briquettes) and it is related to cooling of coal rather than to drying.

The Drying of Brown Coal Containing Pellets

10. The drying apparatus covered by the ECT application is particularly adapted for the drying of pellets containing brown coal. Indeed, it is intended that the drying apparatus will be especially suited for the drying of brown coal containing pellets that have been produced by attritioning brown coal to release finely dispersed water and fracture the coal surfaces exposing reactive molecular species to produce a plastic mass that is extruded to form pellets. Further details of this attritioning and pelletisation process are provided in Johns *et al*, "The conversion of brown coal to a dense, dry, hard material", *Fuel Processing Technology*, 21 (1989), 209-221, a copy of which is shown to me now and annexed hereto as Annexure MLS-2. Prior to being placed into the dryer the pellets may be conditioned with warm air to harden the pellet surface and allow sufficient time for the new phenolic substrate cross linking reaction to commence the densification process. This pre-treatment method of forming brown coal containing pellets causes a fundamental chemical change to the coal structure which serves to free up bound water molecules. The result is that as water is evaporated from the surface of the pellets in the dryer the pellets shrink, thus expelling further water to the surface, which is in turn evaporated causing further shrinkage and expulsion of water to the surface. The drying apparatus covered by the ECT application has therefore been designed such that it promotes evaporation of water from the surface of the pellets, without the need for heating of the pellets. In this way, for example, Latrobe Valley brown coal which has an average moisture content of 60-65% can be dried in an efficient and low cost manner to 12-15% moisture. This process (technically evaporation rather than heating) has a low energy requirement, which is critical in any coal drying approach, as the energy input will have a direct effect on the overall cost.

11. As noted, the drying apparatus covered by the ECT application can be thought of as a low energy evaporator system, utilising ambient air or air heated a little above ambient temperature, preferably by waste heat from a nearby industrial process. The configuration of the dryer allows sufficient free space within the drying apparatus for optimal airflow characteristics to be established to effect evaporation of moisture from the surface of the moist brown coal containing pellets. As noted above, as moisture from the surface of the pellets evaporates the pellets shrink in size causing further moisture to come to the pellet surface, which is in turn evaporated. The configuration of the dryer (having corrugated plate opposed gas permeable walls with ingress and egress openings in the permeable leg) and its height to width ratio contribute to the shrinkage of the pellets as they dry and migrate to lower regions of the dryer resulting in some arching or bridging of the pellets in upper regions of the apparatus. As the pellets dry and contract in size, and have gained sufficient strength, they are released from this supported arched or bridged arrangement and are allowed to progress through to lower regions of the dryer. However, this will only happen when the pellets have assumed sufficient hardness such that when migrating through the dryer they can withstand substantial fracture or deformation. The presence of the ingress and egress openings in the permeable leg rather than the supporting leg of the corrugated gas permeable walls also serves to minimise blockage to these openings, thus assisting to maintain an effective evaporative flow of the drying gas about the pellets.

12. The avoidance of fracture of the pellets mentioned above is most important because of the safety issues that can arise if significant levels of fines are allowed to accumulate in the apparatus. As will be well understood, being a combustible material in the presence of oxygen, where it may not be possible to completely eliminate the presence of an initiation source such as heat or a spark, there is a significant danger of explosion or fire as the level of fines increases – fines material being significantly more combustible than bulk material. Reduction of fines production therefore not only reduces the risk of an explosion or fire, which is obviously important for safe operation and preventing loss of capital investment, but also reduces maintenance costs and minimises the initial capital costs because there is a reduced need for expensive deflagration protection equipment to be installed.

13. Other potential problems that can arise in packed bed drying apparatus include the problems of blockage of airflow ducts, channelling and blowout. These problems are likely to be experienced if the features of the apparatus are not specifically designed with the characteristics of the feed stock material in mind. For example, channelling and blowout may be experienced in a situation where there is a lack of sufficient free space within the material to be dried, such that rather than operating at low drying gas pressure it is necessary to adopt higher drying gas pressures to allow the drying gas to satisfactorily penetrate through the material to be dried. The use of higher drying gas pressures is not only inefficient but would also be likely to result in blowback of the material being dried through the slats between the baffles or louvers of the drier or channelling of the drying gas through the solid material. The characteristic of channelling is well understood in the art to result from the airflow pattern of seeking the path of least resistance. If channelling occurs, large volumes of the drying gas would pass through the channelled region with the result that the gas would not penetrate through the material to be dried and drying is ineffective.

14. Key features of the invention covered by the ECT application that give rise to its adaptation for the drying of brown coal containing pellets include the substantially continuous corrugated plate gas permeable walls, wherein each corrugation comprises a supporting leg and a permeable leg that are angled with respect to each other, and wherein ingress and egress openings are provided within the permeable leg. This arrangement allows optimal airflow characteristics through the drying apparatus and overcomes problems referred to above of blockage of airflow ducts, channelling and blowout.

D1 - PCT/AU02/00824 to Jott Australia Pty Ltd

15. This International patent publication (D1) discloses a fluid/solid interaction apparatus that is disclosed to have a variety of uses, including drying of solid fuels, dust removal from gases, heat exchange, humidifying and de-humidifying. From my reading of the document I understand that the apparatus described is not specifically designed or

adapted for dying of brown coal containing pellets. Indeed D1 discloses that the "solid material" that can be loaded into the apparatus includes granular solids such as wheat or coal or pelletised minerals. Interestingly, the document notes that the fluid that can be passed through these solid materials can be a liquid, such that in fact the apparatus could be used for wetting of materials rather than for drying. While the document does include reference to drying of pelletised brown coal it equally refers to drying of granulated coal or other material. I therefore understand that the apparatus is not particularly adapted for drying of pellets containing brown coal.

16. The apparatus disclosed in D1 includes a plurality of passages extending between a pair of end walls where there is an upper part for receiving solid material and a lower part to which the solid material will flow. The sides of the passages are defined by side walls of a plurality of inlet fluid ducts and outlet fluid ducts that are internal to the apparatus. As depicted in Figure 2 the side walls of the inlet fluid ducts and outlet fluid ducts comprise vertically oriented perforated walls. There does not appear to be any mention that side walls of the fluid ducts could constitute a substantially continuous corrugated plate wherein each corrugation comprises a supporting leg and a permeable leg angled with respect to each other and wherein ingress and egress openings are provided within the permeable leg. Indeed D1 discloses at page 8, third paragraph that the "*apparatus of the invention is preferably designed to have as few horizontal flat surfaces as possible in order to reduce internal dust build up and to avoid impeding the passage of the solid material*". This contrasts the adoption of permeable walls comprising a substantially continuous corrugated plate as defined in the ECT application.

17. In my opinion the substantially vertical permeable wall arrangement disclosed in D1 is highly problematic in relation to drying of pellets containing brown coal and would be prone to blockages. In my view, therefore, the apparatus described in D1 would be unlikely to allow appropriate airflow characteristics for drying of pellets containing brown coal. Furthermore, the open space at the base on the fluid inlet and outlet ducts as shown in Figure 1 would most likely lead to a significant percentage of the drying fluid passing through this region, for it is the path of least resistance. Therefore the

apparatus described in D1 would unlikely deliver the required even distribution of drying fluid across the face of perforated plates.

D2 - US Patent No. 1,482,812 to Roberts

18. This United States patent granted to Roberts in 1924 "*relates to the drying of more or less finely divided material such as diatomaceous earth or other materials which require dehydration or drying in order to render them available for use*" (page 1, lines 9-13). D2 describes a vertical drying apparatus in which material to be dried enters from above and is "*retained by and descends between these opposing baffles or louvre plates, forming a vertical curtain extending the full height of the chamber*" (page 2, lines 8-11). Means are provided for passing a drying medium such as hot gases into chambers adjacent the vertical curtain, with the intention that the drying gas is able to penetrate into the vertical curtain of material to be dried through "*the openings or slots between adjacent baffles*" (page 3, lines 33 and 34).

19. There does not appears to be any direction provided in D2 for the walls of the drying unit to be formed from a substantially continuous corrugated plate, wherein each corrugation comprises a supported leg and a permeable leg and wherein the ingress and egress openings are provided within the permeable leg. There also does not seem to be any suggestion in D2 that the drying unit could be used, or is adapted, for drying of pellets containing brown coal, as it is specifically an apparatus for drying finely divided material. Although D2 refers to "channelling" being prevented (see page 1, line 65), it is highly doubtful that channelling would be prevented in the described arrangement in view of the large openings or slots between adjacent baffles through which air is intended to pass.

20. It is also stated in D2 that "*the inclined supports are arranged so that the enclosed material will move or gravitate in a zigzag manner. This is done for two reasons: first to prevent arching of material between supports....*" (page 3, lines 115-119). This disclosure is interesting because, as I have discussed above, it is in fact desirable in the apparatus described in the ECT application for some arching of the pellets

containing brown coal to take place at least within upper regions of the drying apparatus.

D3 - US Patent No. 3,589,027 to Duzan

21. Document D3 relates to a portable apparatus for drying crops such as corn, wheat, rice and the like (column 1, lines 4-6). The document does not include any suggestion that the drying device it discloses could be used to dry brown coal containing pellets. Indeed, I am confident to say that the dryer disclosed in D3 could not be used to dry brown coal containing pellets, given that the type of dryer disclosed in D3 is a fluidised bed dryer and brown coal containing pellets cannot be fluidised. Even if pellets containing brown coal could be made small enough to theoretically allow them to be fluidised this would not work due to the inherent stickiness of brown coal resulting from its high moisture content.

22. The apparatus of D3 comprises an L-shaped boxlike compartment having a drying section or chamber C and plenum chamber G from which a hot drying gas is delivered to the drying section or chamber. The horizontal walls 17 and 18 of the drying chamber may include baffles 22 that serve to "directionalize the drying gas or air admitted into the drying chamber C" (column 3, lines 2-7), which in one possibility are replaced with a horizontal ruffled wall 30 that is perforated by a series of perforations 30a that provide the desired directional action to the drying gas in much the same way as the baffles 22 (column 3, lines 65-73). In my opinion this arrangement is quite different to the vertical gas permeable walls defined in the ECT application, which are comprised of corrugated plates where each corrugation comprises a supporting leg and a permeable leg and ingress openings and egress openings are provided in the permeable legs. Not only is the orientation of the walls different in the two apparatus but in my opinion the small perforations included within the ruffled walls disclosed in D3 would not allow the necessary volume of low pressure drying gas required for evaporative drying of brown coal containing pellets. In the case of D3 the baffles or ruffled walls act as air diffusers and are required to

minimise channelling that would otherwise be experienced in a high pressure fluidised bed system such as that described in D3.

D4 - US patent no. 5,671,804 to Kordelin

23. Document D4 discloses a heat exchanger element for a film heat exchanger "*suitable for use in a film evaporator or distillation apparatus operating in the thermo-compressor principle*" (column 1, lines 15-17) and which can be used to obtain a distillation product such as fresh water from sea water or purification of industrial wastes. While the heat exchanger element does include a corrugated plate 12 provided with perforations 15 this is in my view of no relevance to the apparatus for drying brown coal containing pellets defined within the ECT application due to the completely unrelated purposes of the two apparatus.

D5 - US patent no. 2,245,664 to Gronert

24. Document D5 dates back to 1938 and relates to a drying shaft for drying granular loose material such as grain, maize, peanuts and the like, which trickle downwards in a shaft and are dried on their passage by air currents produced by a blower (column 1, lines 1-5). The drying shaft disclosed in D5 is completely unrelated to the drying of pellets containing brown coal and in my opinion could not be used for the drying of pellets containing brown coal due to the inappropriate flow of drying gas resulting from the existence of an internal plenum (as opposed to the plenums located on exterior surfaces of the gas permeable walls as defined in the ECT application). The apparatus of D5 is adapted for the drying of loose granular materials, where there is little void space and where a high pressure flow of heated drying gas would be required. This is in contrast to the requirements for drying brown coal containing pellets, where there is a large void space and where a low pressure flow of gas is appropriate to allow surface evaporation of moisture in a cost effective manner. The internal plenum present in the apparatus disclosed in D5 does not include zones of differing air stream properties as required by the ECT application, although zones of differing air stream properties may be present within the main material holding area.

D6 - Herman - "Brown Coal", pages 320-329

25. As is made clear from the title of the chapter of the book "Brown Coal" that is being relied upon as Document D6 – "Briquetting: cooling the dried coal", this document relates to the cooling of already dried coal in the form of briquettes. It has nothing to do with the drying of brown coal containing pellets. The cooling louvers depicted in Fig. 317 are intended to provide a means for controlling the fall and feed rate of the briquettes to thereby minimise their physical damage, at the same time as allowing exposure of the surfaces of the briquettes to ambient conditions to facilitate cooling. The arrangement allows the briquettes to be turned over for maximum surface exposure and heat dissipation. However, this arrangement would not be suitable for the drying of brown coal containing pellets as although some useful bridging of the material may occur there would be a possibility due to the wide open side walls of the louvers that when bridging takes place blowout may occur. Not only is the side wall arrangement disclosed in the ECT application optimal for the drying of brown coal containing pellets (taking into account the material properties and flow rates of material and drying gas) but the corrugated side walls where each corrugation has a supporting leg and a permeable leg provide far greater structural rigidity than the louvred cooling house side walls mentioned in D6. Further in the case of the side walls of the dryer disclosed in the ECT application there is no need for void space beneath the open region of the louvers to prevent material blowout. Due to the structure of the side walls in the dryer disclosed in the ECT application material can come right up to the permeable leg of each corrugation so that there is no waste or void space in the dryer, which is a much more cost effective and efficient approach.

AND I MAKE this solemn declaration by virtue of the Statutory Declarations Act 1959 as amended and subject to the penalties provided by that Act for the making of false statements in statutory declarations, conscientiously believing the statements contained in this declaration to be true and correct in every particular.

DECLARED at Melbourne, Australia this 21st day of January, 2011.

Matthew Lloyd-Smith.

Before me:

PAULA DE BRUYN
1 Nicholson Street, Melbourne 3000
Registered Patent Attorney
within the meaning of the
Patents Act 1990

[Name] , Witness

AUSTRALIA

Patents Act 1990

IN THE MATTER of Australian Patent
Application No. 2004274520
in the name of ECT Coldry Pty Ltd

- and -

IN THE MATTER of Opposition thereto
by Jott Australia Pty Ltd

This is Annexure MLS-1 referred to in the Statutory Declaration of Matthew Lloyd-Smith made before me.

Dated this 21st day of January, 2011.

PAULA DE BRUYN
1 Nicholson Street, Melbourne 3000
Registered Patent Attorney
within the meaning of the
Patents Act 1990

ARUP

Matthew Lloyd-Smith

Profession

Senior Mechanical Engineer

Current Position

Associate

Joined Arup

January 2005

Qualifications

BEng

CPEng

NPER

Professional Associations

Member, Institution of Engineers Australia (MIE Aust)

Member, Logistics Association of Australia

Key Data

Matthew Lloyd-Smith is an Associate within the Industrial Division and leads the Process Engineering Team of the Melbourne Office.

Since joining Arup five years ago he has worked on a diverse project portfolio in the following key markets sectors:

- Manufacturing and Industry
- Water and Wastewater
- Mining and Resources
- Energy and Renewable

Matthew has a solid engineering background combined with commercial, facilitation, strategic alliance, innovation and leadership experience. His diverse experience is particularly valuable in the industrial market sector, covering pre-feasibility studies through to detailed design of complex multi-stakeholder and cross-disciplinary projects. Matthew's technical skills are best directed towards the integration of new technology, innovation and equipment design associated with new industrial plants, facility expansions and process upgrades. Matthew's interests are in complex projects that involve an integrated design and delivery process, which requires carefully consideration of sustainability and financial challenges and interactions between the operational, safety, cultural and environmental factors.

He has over 18 years experience in the industrial sector and his fields of expertise is typically in bulk materials and bulk powders handling, processing, storage, conveying, heating and drying. These skills are complimented by his background in industrial ventilation, thermodynamics, dust and fume control and air handling systems for process drying, cooling and heating.

Matthew's technical skills and engineering experience in the manufacturing sector covers facility design, lean production, operations research and logistics, process integration and optimisation, process and equipment performance specification, project estimating, simplified financial modelling, risk assessment, HAZOP facilitation and commissioning.

Selected Drying Process Projects

Environmental Clean Technologies – Latrobe Brown Coal Drying Facility (2008-09)

Project Design Leader for the feasibility design, engineering (process, mechanical, electrical, structural and civil), drafting, 3D modelling and process equipment specifications for a brown coal dewatering and drying facility. Scope of design includes coal receival hoppers, screening, milling, extruding, conveying, drying in packed bed hoppers, drying air recirculation fans, heat exchanges, dehumidifiers, coolers, chiller plant equipment, pumps, piping reticulation, process controls and instrumentation, and other supporting infrastructure and services.

Clay Dryer - Imerys Minerals Australia (2003-04)

Project Leader for the design, manufacture, supply and installation of a six zone,

ARUP

Matthew Lloyd-Smith

26 meter long, direct gas fired continuous conveyor band dryer processing 24 tonnes per hour of extruded kaolin pellets. The equipment design covered recirculating fans, conveyor drives, gas burners, valve trains, monitoring and burner management systems. The project scope also encompassed the main control cubicle, motor control centre, exhaust fans and ducting, moisture monitoring system, waste pneumatic conveying system and central dust collection system.

Sugar milling plant upgrade and process air system – CSR Sugar Australia (2008-09)

Design review consultant responsible for the upgrade of the industrial and retail icing sugar milling circuits. Lead design review engineer for the sizing and selection of the lean phase pneumatic conveying systems, positive displacement blowers, mill air supply equipment, dehumidifiers, chilled water plant and process air cooling, dust control, dust filters and associated materials handling equipment. Preparation of process control philosophy and function description.

Zinc Oxide - Larvik Pigments, Footscray (1998-99)

Design engineer and project manager for three high temperature bag houses for the collection of zinc oxide from three boiler exhaust combustion chambers. Including bulk material transfer equipment and lean phase pneumatic conveying system for feeding product to bagging silos.

Mineral Sands Drying and Reheating – General (2003)

Design and engineer of static and vibrating type fluid bed dryers and reheaters for ilmenite, rutile and zircon bulk product. Scope encompassed air delivery and exhaust fans, gas fired heaters, material feed equipment, dust collection system, instrumentation and process controls.

Full Panel EOE Drying Oven Facility Upgrade – Visypak Food Packaging (2008-09)

Project Manager for the facility design upgrade, process equipment integration, preparation of design brief, process equipment specifications, drafting, installation and commissioning of two tin lid scour repair drying ovens, solvent decanting and delivery system, solvent/lacquer mixing system, oven flue exhaust system, ducting, fans and regenerative thermal oxidiser.

Scour Plate Oven Repair System – Visypak Food Packaging (2007-08)

Engineering services for the design modifications of a tin lid (easy open end) repair oven for curing the coating lacquer. Design modifications covered the specifications to meet AS 3814 covering electrical, PLC design, controls, flue design, fan sizing and valve train modifications.

Cheestik Drying System – Kraft Foods (2004)

Design engineer responsible for conceptual design and Project Leader for cheese-stick vibratory conveying, de-watering and drying system integrated within existing plant equipment.

Lime Processing Plants - Unimin Minerals (2002-03)

ARUP

Matthew Lloyd-Smith

Engineering studies, audits and reporting of capital processing equipment, materials handling and dust control requirements, upgrade and process optimisation for lime kilns, rotary dryers, mills, crushing and screening plants at Lilydale (VIC), Traralgon (VIC), Attunga (NSW), Mole Creek (TAS) and Tamaree (QLD).

Lime Kiln – Unimin Minerals, Tamaree, QLD (2002-03)

Engineer and design of high temperature bag house for the flue gas particulate collection from a fluidised bed lime kiln fired on macadamia nut husks.

Lime Kiln Upgrade - David Mitchell Limited, Traralgon (2000-02)

Lime kiln bag house plant upgrade. Design engineer and project engineer the upgrade of one high temperature kiln flue gas exhaust bag house and fan to accommodate increased kiln output demand.

APPC – Pistachio Nut Drying System (2003-04)

Design engineer responsible for conceptual design and project manager for custom designed pistachio nut vibratory conveyor and direct gas fired drying system, including integration of equipment into the existing production plant.

Chemical Product Storage Dryer – Bostik Findley (2003-04)

Project Leader for design and construction of heated storage facility for temperature sensitive bulk powders and liquids.

AUSTRALIA

Patents Act 1990

IN THE MATTER of Australian Patent Application No. 2004274520 in the name of ECT Coldry Pty Ltd

- and -

IN THE MATTER of Opposition thereto by Jott Australia Pty Ltd

This is Annexure MLS-2 referred to in the Statutory Declaration of Matthew Lloyd-Smith made before me.

Dated this 21st day of January, 2011.

PAULA DE BRUYN
1 Nicholson Street, Melbourne 3000
Registered Patent Attorney
within the meaning of the
Patents Act 1990

Fuel Processing Technology, 21 (1989) 209-221
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

The Conversion of Brown Coal to a Dense, Dry, Hard Material

R.B. JOHNS, A.L. CHAFFEE* and K.F. HARVEY

Dept. of Organic Chemistry, University of Melbourne, Parkville, 3052 Victoria (Australia)

and

A.S. BUCHANAN and G.A. THIELE

CRA Advanced Technical Development, 55 Collins Street, Melbourne, 3000 Victoria (Australia)

(Received July 18th, 1988; accepted October 21th, 1988)

ABSTRACT

A technology has been developed for transforming run-of-mine brown coals into a dense, dry, hard product. Raw coal is attritioned in batch or continuous kneaders to a mean particle size of approximately 10 μm. This size reduction releases the water naturally occurring within the porous coal structure, such that a paste-like material results. The paste can then be easily formed into products of the desired shape and size by extrusion devices. A hard, low-moisture content briquette-equivalent product is produced by the evaporative removal of water at or near ambient atmospheric drying conditions. The resultant product exhibits considerable strength, which may be further improved by the addition of pH modifiers in the case of suitable coals. Advantages of this densified brown coal process are that a hard, dense, fuel product can be manufactured from a raw brown coal of high initial water content without the need for, or prolonged, expensive drying conditions at elevated temperature. The resultant product is suitable either as a briquette equivalent fuel, or as feedstock for the manufacture of smokeless fuels, chars and activated carbons. The product retains the Volatile and Fixed Carbon values of the raw coal but possesses a Net Wet Specific Energy equivalent to that of a high rank coal. The densified coal has an advantage over a black coal in that dependant upon the coal stock selected the mineral content can be quite low. The process is more general and has been applied to other feedstocks — a peat and some lignites as well as brown coals have been found suitable. The chemical analyses indicate the involvement of phenolic residues in the coal as reactive centres. Reactions of these residues are initiated by the shearing-attritioning step in which fresh and reactive surfaces of the coal particles are exposed. The reactive centres are brought together by extrusion allowing cross-linking reactions to occur during drying.

INTRODUCTION

Australia is rich in brown coal, with the state of Victoria alone having reserves of some 202,000 million tonnes (Mt), of which 43,000 Mt is regarded as

*Present address: CSIRO Division of Fuel Technology, PMB 7, Menai, 2234 Australia.

0378-3820/89/$03.50

readily recoverable [1]. The Latrobe Valley deposit in Victoria is equivalent to about 25% of known world reserves, the coal seams are generally of considerable thickness, and are covered by little overburden. This coal is recovered cheaply in large efficient open-cut mines. Currently some 40.5 Mt of coal is mined annually [1] and the Reserves/Production ratio is 1,170 years, a very favourable figure when compared with East Germany (43 y) or the U.S.A. (516 y).

When compared with black coals, this brown coal is seen to be a relatively clean material, having very little ash and sulphur (Table 1). However, these benefits of ready accessability and product quality are offset by the high water content of the coal — which is often in excess of 60% by weight. Freight costs on a dry basis are such that 93% of production is burnt for electricity generation adjacent to the mine sites. The remaining coal is used locally for briquette manufacture or as a fuel.

Direct removal of moisture from the run-of-mine brown coal prior to transportation is not an available option for increasing the energy or dry coal content per tonne of material. The soft, friable, low density coal dries to a weak and dusty material that is prone to spontaneous combustion and is therefore hazardous to transport [2]. Three percent of the mined coal is crushed, dried and pressed into briquettes. It is this hard and non-pyrophoric product containing approximately 18% moisture, which is transported to regional and international markets.

Alternative processes for the conversion of raw brown coal to a high quality fuel are being sought. One of the more promising processes being developed is known as Solar Dried Brown Coal Slurry [2]. In this process, raw brown coal is milled in added water to give a very fine concentrated suspension. The slurry

TABLE 1

Comparison of black and brown coals with densified brown coal from the Morwell (Vic.) seam

	Brown coal Morwell, Vic.	Black coal Tarong, Qld [5]	Densified brown coal
Moisture	59.3% wb	5.2% adb	15.9% adb
Volatile matter	49.2% db	29.7% db	48.9% db
Fixed carbon	48.8% db	40.9% db	49.1% db
Ash	2.4% db	29.4% db	2.4% db
Total sulphur	0.3% db	0.42% db	0.3% db
GSE	27.2 MJ/kg daf*	31.98 MJ/kg daf	27.2 MJ/kg daf
NWSE	8.4 MJ/kg*	21.3 MJ/kg adb	22.0 MJ/kg adb
Bulk density	1130 kg/m^3	–	1200–1700 kg/m^3

wb - wet basis, adb - air dry basis, db - dry basis, daf - dry ash free basis, GSE - gross specific energy on a dry ash free basis, NWSE - net wet specific energy.

* - Reference (1).

is pumped into drying ponds, where it loses water by evaporation and cracks on exposure to sun and wind, leaving a hard, dense lump product. With a water content in the vicinity of 12%, it is an excellent fuel. It does not redisperse in water, and degrades less than briquettes when exposed to the weather. The solar dried brown coal slurry process is a potentially cheaper operation than briquetting, but there are some significant disadvantages in the process:

(a) substantial extra water must be added to the coal and later removed,
(b) attritioning in high speed rotating plate mills is required,
(c) the limitation on slurry depth during drying necessitates very large evaporating ponds,
(d) residence time of the coal in the ponds can vary from weeks to months — depending on weather and hence evaporating conditions.

Overall, the product will be relatively costly especially when compared with the low mining costs of the original coal.

The densified brown coal process (3) described in this paper avoids many of the shortcomings of the existing and other proposed processes for conversion of brown coal and has the potential to produce a quality fuel as well as a substrate suited to alternative uses of brown coals. Additionally, the process is wider in its application since peat and some lignites (Table 2) can also be converted to a densified, hard form.

TABLE 2

Compressive Strengths of densified coal pellets derived from a range of low rank raw coals

Raw coal	Compressive strength, σ_c	pH of raw coal
N 3372 (D)	36.5±1.2	3.4
M 2276 (D)	40.9±2.6	3.6
LY 1276 (D)	13.4±1.7	3.2
C 92 (MD)	1.6±0.3	2.9
H 1317 (L/ML)	28.5±5.8	4.7
Morwell ROM	28.4±6.9	5.3
Maddingley	29.3±2.8	7.1
Esperance (W.A.)	7.6±0.8	6.7
Roxburgh (NZ)	35.9±9.2	5.3
Sri Lankan Peat	24.6±2.7	4.2

N 3372 (D) = Morwell No. 1 seam (dark lithotypes) Narracan bore hole No. 3372.
H 1317 (L/ML) = Morwell No. 1 seam (light/medium light lithotype).
LY 1276 (D) = Morwell No. 1B seam (dark lithotype).
C 92 (MD) = Traralgon No. 2 seam (medium dark lithotype).
M 2276 = Yallourn seam (dark lithotype)
Compressive strengths were determined on dry 10 mm pellets prepared from "as-received-coals" with 5 h of kneading.

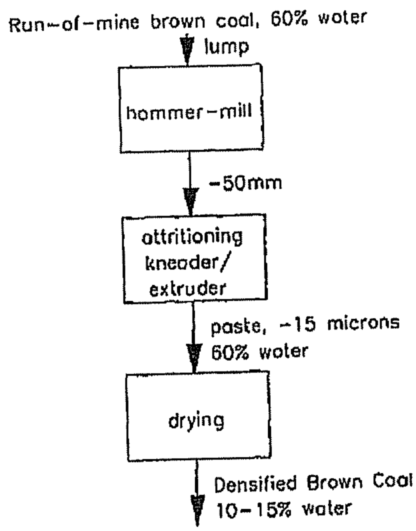

Fig. 1. Densified Brown Coal Process.

The densified brown coal process

The densified brown coal (DBC) process is shown in Fig. 1. Here run-of-mine brown coal, containing approximately 60% by weight water is hammer-milled to less than 50 mm lumps and then fed to a low intensity shearing attritioner.

The discharge from the attritioning mill has a mean particle size of approximately 10 μm. This reduction in particle size effectively releases the water that has been trapped within the porous structure of the raw coal. The water is dispersed throughout the matrix and results in the coal being transformed to a moist plastic mass, not unlike wet clay in consistency. This state of coal is achieved without the addition of any extra water.

The plastic attritioned coal is next extruded into pellets or blocks of the required dimensions. Both piston in cylinder type extruders and screw extruders, in which air entrained within the paste is removed by vacuum, are suitable product forming devices. The moist product is then conveyed for drying, which takes place by evaporative loss of water to the atmosphere.

EXPERIMENTAL

Feed types

A wide range of peats, brown coals and lignites have been successfully treated by this process. The work reported here was conducted chiefly on brown coals

from the Latrobe Valley brown coal fields in Victoria, Australia. Some results using coals from elsewhere in Australia, New Zealand and a Sri Lankan peat are also included.

Attritioning

Run-of-mine brown coal containing approximately 60 wt.% of water is hammer-milled to less than 50 mm size and fed to a low intensity shearing attritioner (Fig. 1). Suitable industrial attritioners are, for example, sigma blenders (or z-arm blenders) or the mixer kneaders used to manufacture carbon anodes in the aluminium industry. In a batch process 0.4 to 1.8 kg quantities of coal are attritioned; in pilot scale runs feed rates of 20–64 kg/h were used. The particle size of the brown coal is reduced to 5–10 μm by the shearing action of the kneader.

Attritioning is continued only until the coal assumes the form of a moist plastic mass which is then extruded into pellets or blocks of the required dimensions. In laboratory batch experiments attritioning times can be shorter than 5 minutes or up to several hours, depending upon the purpose of the experiment. In pilot scale runs the rate of throughput of coal has been found to be limited by the capacity of the feed system since residence time of the coal in the kneader can be of the order of 1 minute or less to produce an extrudable paste.

Additives

Additives that increase the pH of the attritioned coal have been found to be effective in improving the strength of the densified product. These additives are conveniently added as aqueous solutions or fine solids during the attritioning process to give the desired loading and in this manner thorough mixing was readily achieved.

Product forming

The moist paste was extruded into cylindrical pellets either by means of a piston-in-cylinder or screw extruder. In a continuous process, the coal-paste was extruded through dies having diameters of 8, 25 and 46 mm. The green product is then conveyed for drying. The data reported here is for pellets of 10 mm diameter unless noted otherwise.

Product drying

Extruded pellets were stacked into shallow beds for drying, which was conducted at ambient conditions (20°C and 55% relative humidity) with or without draught assistance. Higher temperatures were employed in some instances.

Measurements

The quality of the attritioned coal paste was readily monitored and assessed in terms of hand penetrometer measurements which are a measure of load-bearing ability, i.e., the force necessary to press a 25.4 mm (1 inch) diameter plunger 6.4 mm into the paste.

Compressive strengths of the pellet and strands of the extruded densified coal were monitored by measuring the height (H) and diameter (D) of pellets to be tested. These were then placed on the anvil of a Universal Testing Machine (Tirius Olsen Testing Machine Co., Willor Grove, Pa) and an axial load applied across the plane ends until failure occurred. The compressive strength σ_c was calculated from the force F, determined from the maximum load the pellets withstood, according to the formula:

$$\sigma_c = (4F/\pi D^2)\ (H/D)^{0.5} \quad (1)$$

The pH measurements reported here were determined by adding a sufficient but constant volume of distilled water (pH 5.4) to the moist attritioned coal so as to produce a dispersion of the coal in water capable of fully wetting the glass electrode. The pH measured will be primarily determined by soluble acids from the coal but will be influenced also by surface acidic groups on the dispersed coal particles.

RESULTS

Paste formation from brown coals

The ease with which brown coals are transformed from their crumbly particulate state into pastes is coal-dependent as can be seen from Fig. 2.

Additional tests have been conducted on 20–64 kg/h continuous kneaders. These tests have confirmed that industrial equipment is available that is well-suited to attritioning brown coals. The power consumption for this size reduction has been measured at approximately 40 kW h^{-1} (ton of paste)$^{-1}$.

The size reduction effectively released the water trapped within the pore structure of the raw coal and resulted in the coal being transformed to a moist plastic mass, not unlike wet clay in consistency. The plasticity of the pastes were determined using a hand penetrometer; pressures <0.9 kg/cm^2 (88 kPa) were generally indicative of a coal paste suitable for extruding and drying.

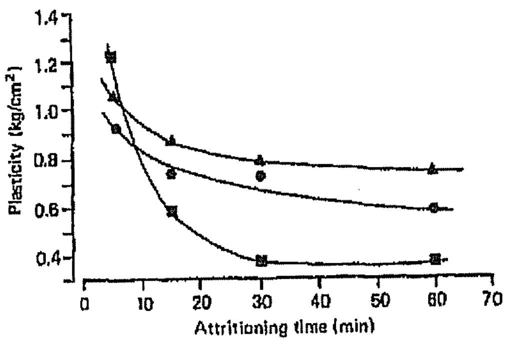

Fig. 2. Paste forming characteristics of three coals. ■ = Loy Yang, 62% water content; ● = Morwell 57.3% water; ▲ = Maddingley 60.3% water.

Figure 2 illustrates the unique response of each coal to attritioning, with Loy Yang coal forming the softest pastes. Water content alone did not determine the ultimate plasticity achievable, as the driest coal (Morwell) initially formed a softer paste than the wetter Maddingly coal. This points to chemical factors determined partly by coal lithotype and secondarily, mineral and ash contents as being important. In practice, short attritioning times giving limited size reduction of the coal particles and a stiffer paste can be compensated to some extent by the subsequent use of high extrusion pressures. A relatively dry plastic mass will lead to the development of high pressures in the nozzle region of the extruder.

Drying of extruded densified brown coals

The behaviour of moist extruded pellets (10 mm original diameter) as drying progresses following extrusion, is illustrated in Fig. 3. The brown coals used are a Latrobe Valley, Victoria, coal (Figs. 3a–c) from the Narracan 3372 borehole with 5% fine magnesite added during attritioning, and Maddingley coal (Fig. 3d). The results are fully representative of the behaviour of typical Victorian brown coals. Drying in still air (20°C, 55% relative humidity) has been compared with forced air assistance (0.5 m/s, 20°C, 55% relative humidity).

Rate of water loss in forced air (Fig. 3a,d) is quite rapid and is essentially complete in 10–12 h, whilst in still air the rate of loss is much less but still rapid (approx. 75% complete in 24 h). Subdivision of the coal into small pellets is beneficial in achieving these high rates — a large (400 g) mass of coal requires many days to dry to an equilibrium state.

Volume decrease (Fig. 3b) lags behind water loss initially but is complete after a similar period of time. In the example given the volume decreased to half its initial value, but this can be greater when no inorganic material is added to the raw coal.

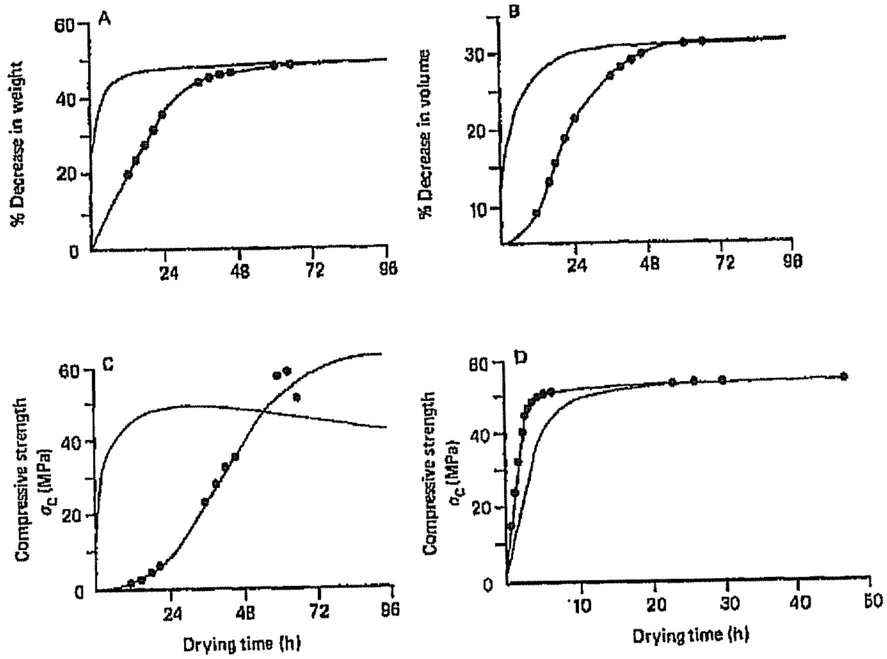

Fig. 3. Drying behaviour of densified brown coals in still (●-●) and in forced draught (—) conditions. A, B and C = Morwell coal (Narracan bore) containing 5% magnesite. D = Maddingley coal. (5 h kneading in each case, 55% relative humidity, 20°C; forced draught of 0.5 m/s). D — = 10 mm pellets; ●-● = 3 mm pellets, both under forced draught conditions.

The rate of increase of compressive strength is again quite rapid in forced air (maximum strength is attained in about 24 h, Fig. 3c). However as time elapses further, the compressive strength becomes variable. This effect appears to be due to shrinkage cracking of the pellets which accompany uneven drying in the forced air stream. In still air, development of compressive strength in the first 24 h is slower. Over the next 48 h the increase in strength is rapid up to the maximum. The compressive strength remains approximately constant with the further lapse of time. In contrast with forced air drying these uniformly dried pellets display few cracks and have relatively high compressive strengths. The pellets may be piled after the first 24 h. Heat assisted loss of water from the pellets may also be used to accelerate the hardening process. Oven drying in still air at 30–50°C is effective in producing hard pellets in a comparatively short time span, but with some reduction in ultimate strength.

Compressive strength of DBC as a function of lithotype

The lithotype composition of the brown coal has been found to have a marked influence on the strength of the densified product (Fig. 4). In general the lighter

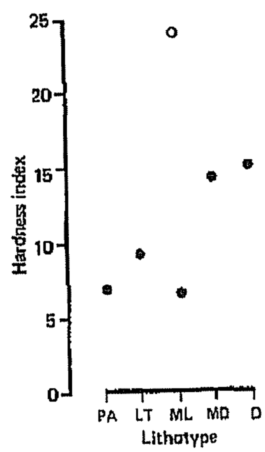

Fig. 4. Knoop Hardness Index of densified brown coal (10 mm pellets) as a function of coal lithotype. ● = Loy Yang coals; O = Morwell coal. PA = pale lithotype; LT = light; ML = medium light; MD = medium dark; D = dark.

lithotypes [1] provide the weaker densified products but there is also variation between coals from different seams. As shown in Fig. 4, a coal from the Morwell seam provides a much stronger product than coals from the several boreholes in the Loy Yang seam. Compositional differences between coals from various seams will probably account for part of the differences in densification behaviour. It has also been established that the more acid coals densify less satisfactorily and yield weaker products (Table 2). Coal pH is known to vary as function of lithotype within given seams [6].

Compressive strength as a function of pH

The influence of pH on the compressive strength of three densified brown coals is illustrated in Fig. 5 and is shown to be an important chemical parameter determining compressive strength for naturally acidic coals. The trend for related coals is for the compressive strength to increase as pH is raised. Morwell coal with an 'as-mined' pH of 4.6 densifies better than Loy Yang coal at a more acidic pH of 3.7 for the raw coal. Additives which are effective in raising pH and hence strengthen the densified brown coal include $Mg(OH)_2$, $MgCO_3$, $CaCO_3$, Na_2CO_3 and NH_4OH..

Sodium carbonate has proved to be a particularly effective additive especially when added to the naturally acidic coals. Loy Yang light lithotype has a natural pH of 3.7 and this is increased to 5.4 by addition of 0.4% Na_2CO_3. The addition causes the compressive strength of the densified product to increase from 11 to 32 MPa. For comparison, the compressive strength of commercially available Latrobe Valley briquettes is approximately 16–22 MPa.

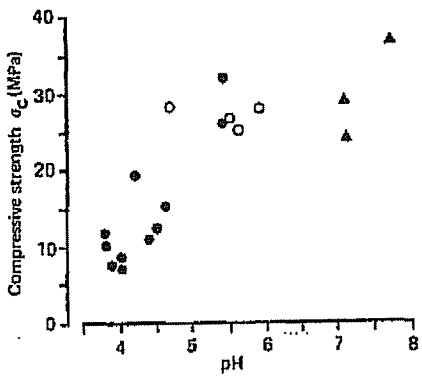

Fig. 5. Compressive strength of densified brown coal (10 mm pellets) as a function of the pH of densified coal slurries; ● = Loy Yang coals; ○ = Morwell No. 1 seam, H 1317 bore coal; ▲ = Maddingley coal.

DISCUSSION

The production of a densified, dry, hard form of coal as described here has novel features which reflect the complex physical structures and chemical components comprising the brown coals, lignites and peat which have been tested as raw materials for this process and are listed in Table 2. One major advantage in the procedure is that it leads to a coal which can be moulded to a desired shape drying to an end product of much higher calorific value (Table 1). This ability to form moulded shapes allows the product to be adapted for immediate application in uses other than simply as a fuel. Additionally, ambient temperature drying preserves the volatile chemical constituents of the raw coal through to the densified coal (Table 1). The advantages of the coal for alternative uses such as a feedstock for the production of activated carbons and chars used in metallurgical applications and synthesis gas production are still retained.

The length of time attritioning is continued is in part dependent upon the characteristics of the kneader selected and in part on considerations of energy consumption. The more plastic the coal the easier it is to extrude and the less the energy consumption at that step. Figure 2 demonstrates that plasticity is coal dependant but that there is an optimum kneading time to reach a minimal plasticity which is economical in energy terms. When compressive strength is taken as the desired criterion for determining attritioning time, Fig. 6 dem-

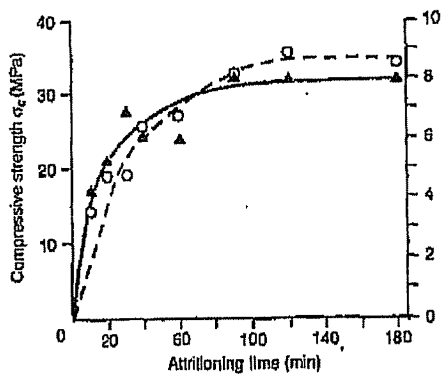

Fig. 6. Compressive Strength of the densified coal product as a function of Attritioning Time for Morwell (○) and Loy Yang (▲) coals. Note that Loy Yang coal is plotted to a maximum scale of 10 MPa.

onstrates that there is an optimum period for the production of a suitably strong product. Because attritioning is also machine dependant, the degree of offset from the typical curves shown in Fig. 6 must be determined experimentally for the coal and the kneader selected.

The procedures described here [3] imply a flow of chemical reactions initiated by a distinctive attritioning-shearing step. The original microstructure of the coal is destroyed to a significant extent in this initial step, releasing finely dispersed water which coalesces with the dispersed coal fragments to form a plastic mass. This small particulate form of coal is now able to move freely and reassociate effectively during densification. Shearing has the additional action of creating newly fractured coal surfaces and exposing reactive molecular species which are able to participate in new bond-forming reactions some of which will form early in the shearing process. In keeping with the chemical cross-linking implied above, a significant temperature rise is often observed in the coal mass during the attritioning period. Humic acid constituents [4] of Victorian brown coal are bound covalently into the densified products and consistent with their predominant phenolic nature we propose that reactive molecular species derived from phenols are involved in bonding reactions. The pH control on the compressive strength as illustrated in Fig. 4 is good circumstantial evidence for phenolic substrate involvement in the cross-linking associated with the densification process. The drying of the extruded 'green' coal should also be understood in those molecular terms and during which process the coal particle surfaces continue to bond together — the strength of the product reflecting the extent of cross-linking which can occur.

The pH effect is more significant with naturally acidic coals and as Table 2 shows is only useful in general terms when comparing unrelated coals. Compressive strength is evidently only responsive when the acidity of the raw coal

shows a pH of approximately <4.5. The data emphasize coal structure reflecting environments of deposition (and thus contributing flora) to be a parameter of potentially over-riding significance in determining the magnitude of the several effects identified in this paper.

CONCLUSIONS

(1) Densified brown coal can be prepared using raw brown coal, with an asmined water content as the sole raw material. Only the water originally present in the coal need be removed by subsequent drying. This is a distinct advantage over current procedures aimed at producing a dewatered product.

(2) Attritioning of the coal can be performed in large, energy efficient kneaders. High capacity industrial scale attritioners have been tested and found suitable for continuous production of large quantities of coal paste.

(3) The moist plastic product from the attritioning step is easily extruded in an integral operation to give a product of optimum form and size which is immediately adaptable for uses in addition to those as a fuel.

(4) This freshly extruded product can be dried by evaporative water loss to the atmosphere at ambient temperatures to give a 'densified' brown coal. The compressive strength which can equal that of briquettes or hard coals, will depend upon the chemical composition of the coal used, the pH and the rate of drying.

(5) As a consequence of water loss densified brown coal has a calorific value equivalent to that of a high rank coal. It possesses abrasion resistance and is readily transportable. The densified coal compares then, with a harder black coal but can have an advantage, dependant upon the raw brown coal used, of a low mineral content which is often not the case for black coals. The percent Volatile and Fixed Carbon values of the raw coals are retained suggesting that the chemical reactivity of the raw coal should also be substantially retained in the densified product.

ACKNOWLEDGEMENT

The authors thank Mr A.G. Pandolfo for providing the data in Fig. 6.

REFERENCES

1 Perry, G.J. and Allardice, D.J., 1987. New Research and Development initiatives for the use of Victorian brown coal. Coal Res. Conf. N.Z. Proc. I, Section 4, Paper R 4.1.

2 Woskoboenko, F. and Stacey, W.O., 1985. The solar dried coal slurry process. Proc. 1985. Int. Conf. Coal Sciences, Sydney, pp. 505–508.

3 For example: Johns, R.B., Chaffee, A.L., Cain, D.A. and Buchanan, A.S., 1986. Upgrading Solid Fuels. US Patent 4,627,575; Harvey, K.F., Johns, R.B., Buchanan, A.S. and Cain, D.A., 1987. Upgrading Solid Fuels (Patent-of-Addition to the above). US Patent 4,701,184.

4 Verheyen, T.V. and Johns, R.B., 1981. Structural investigations of Australian coals I. Geochim. Cosmochim. Acta, 45: 1899–1908.

5 Brockway, D.J. and Chalmers, D.P., 1986. Chemical Assessment of Coal for Power Generation. Chemistry in Australia, pp. 193–197.

6 Perry, G.J., Allardice, D.J. and Kiss, L.T., 1984. The Chemical Characteristics of Victorian Brown Coal. In: Schobert, H.H. (Ed.), The Chemistry of Low-Rank Coals, ACS Symposium Series No. 264, pp. 3–14.